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DIFFRACTIVE LIGHT MODULATOR

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Application No. 60/458,761, filed March 28, 2003 by inventors Alexander Payne et al. and entitled "High Speed Diffractive Light Modulator." The disclosure of U.S. Provisional Application No. 60/458,761 is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field Of The Invention

The present invention relates generally to micro electromechanical systems (MEMS) and, more particularly, to diffractive light modulators.

2. Description Of The Background Art

A MEMS or micro electromechanical (MEM) device typically includes micromechanical structures or light modulators that may be actuated using electrical signals. The light modulators may comprise, for example, Grating Light Valve™ (GLV™) light modulators available from Silicon Light Machines, Sunnyvale, CA (GLV™ and Grating Light Valve™ are trademarks of Silicon Light Machines). A light modulator may include an array of moveable structures referred to as "ribbons." Light modulators may be used in various applications, including video, printing, optical switching, and maskless lithography, as just a few general examples.

FIG. 1 illustrates a conventional diffracting element surface structure **100** that can be part of a light modulating device. This structure includes two surface levels, with one generally movable and one generally fixed. These are labeled as "upper" **102** and "lower" **104** reflecting surfaces in FIG. 1. Each of these surfaces has substantially equal area and equal reflectivity properties. Also, the height difference between each surface (i.e., in the direction of the light to be modulated) is changed to modulate the relative phase difference for light reflected from each surface. If, upon reflection, the light from both surfaces is "in phase," then the 0^{th} order light reflection is effectively maximized. If, upon reflection, the light from both surfaces is "out of phase," then the 0^{th} order light reflection is effectively minimized. To minimize the 0^{th} order reflection, the height difference can be $1\lambda/4$, $3\lambda/4$, $5\lambda/4$, $7\lambda/4$ or $9\lambda/4$, etc., where λ is the wavelength of the incident light. To maximize the 0^{th} order reflection, the height difference can be $2\lambda/4$, $4\lambda/4$, $6\lambda/4$, $8\lambda/4$ or $10\lambda/4$ etc. These maximum and minimum 0^{th} order reflectivities may only be realized with an optical system that can appropriately discriminate between various diffraction orders. Typically, within one modulating element, the spatial frequency of these surfaces must be greater than that of the modulating element. In many implementations, it is at least twice as much. For the example case illustrated in FIG. 1, a "pixel" can include at least 2 upper surface reflecting features and 2 lower reflecting surfaces. Similarly, optical systems can be built which may select diffracted light, and the diffracted light can be modulated from about a maximum to about a minimum value in the same manner.

FIG. 2 is an illustration of a conventional light modulator in both cross section and top view. This represents a very particular example implementation where “ribbons” are used as modulator elements. In this example, the ribbons **202** and gaps **204** are the same width. Also, the ribbons **202** and gaps **204** are typically a uniform width for their entire length. Further, the gaps **204** and ribbons **202** are typically covered with the same reflecting material **206**, which can be Aluminum or other reflective material. The height difference, as related to the cross section diagram, is initially controlled by the film thickness choice. The height difference (and hence the reflective or diffractive condition of the modulator element) can be changed by controllably deflecting the ribbons **202** by up to about $\lambda/4$, where λ is the wavelength of the incident light. Here, It is assumed that the light is at or near normal incidence, i.e., perpendicular to the plane of the device. Accordingly, in the cross section diagram, the light direction would be from the top of the page to the bottom of the page. In the top view diagram, the light direction would be onto the page in a direction normal to the page.

FIG. 3 shows an illumination profile **301** for a conventional diffractive element **300**. When the ribbons **302** are deflected, they are approximately parabolic in shape, as shown, along their length. The center portion **304** of the ribbons **302**, perhaps the middle third, has a relatively flat profile, and this deflection **306** may be set to $\lambda/4$. However, the entire ribbon or diffractive element length does not have a uniform deflection. In fact, the section near the support posts **308** on either side does not deflect at all. Thus, the best optical condition can only be achieved in the middle region **304** of the ribbon **302**. In practice, the optical illumination can be substantially restricted to this central region **304**. This is typically referred to as the “sweet spot” or “optically

active area." In order to achieve both high efficiency and contrast, the light must be restricted to approximately the middle 1/3 of the ribbon or diffractive element length.

It would be desirable to have a light modulator design that included diffractive elements optimized to take advantage of the limited optically active areas for improved overall modulator performance.

SUMMARY

In one embodiment, a light modulator can be configured to have a substantially flat optically active modulator element portion while deflected. The modulator can include a plurality of modulator elements arranged substantially in parallel, with each modulator element including an optically active portion and a support portion on either side of the optically active portion. Further, the optically active portion can have a narrower width than the support portion.

In another embodiment, a movable membrane for light modulation includes a substantially circular optically active portion and a released membrane portion surrounding the circular optically active portion. The substantially circular optically active portion can also include a plurality of gaps configured to expose a lower surface. Further, the substantially circular optically active portion can be essentially flat while in a deflected state.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a conventional diffracting element surface structure.

FIG. 2 is an illustration of a conventional light modulator in both cross section and top view.

FIG. 3 shows an illumination profile for a conventional diffractive element.

FIG. 4 is a diagram showing an optical area and a released membrane area.

FIG. 5 is a top view of a light modulator structure according to a first embodiment.

FIG. 6 is a top view of a light modulator structure according to a second embodiment.

DETAILED DESCRIPTION

Described herein are embodiments suitable for modulating incident light beams on a light modulator. In the interest of clarity, not all features of an actual implementation are described in this specification. It will be appreciated that, in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals. Such details might include compliance with system-related and business-related constraints, which will vary from one implementation to another, for instance. Moreover, it will be appreciated that such a development effort, even if complex and time-consuming, would be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

FIG. 4 is a diagram showing an optical area (inside the dot-dash circle) **402** and a released membrane area (outside the dot-dash circle) **404** of a device **400**. Similar to the ribbon diffractive element example case described above, because the center portion of the ribbon or membrane is the optically active area **402**, this area **402** may be

weighted equally between the upper surface **406** and lower surface **408**. In particular, a substantially equal optical energy (i.e., a product of area times a reflectivity) may be created. For example, the upper surface **406** may comprise a center portion of a membrane, and the lower surface **408** may comprise areas of a reflective substrate below the multiple openings or gaps in the membrane. FIG. 4 depicts arbitrarily-shaped openings or gaps to illustrate that such openings may be of various shapes. Along these lines, the optically active area **402** is the only area that would actually benefit from having a uniform cross section (i.e. flat surfaces).

The remaining ribbon or membrane area **404** can be used to tailor or optimize for other properties of the device. For example, the device switching speed can be optimized by taking advantage of this portion of these device properties. Here, a diffracting light modulator device is described. The modulator can include maintaining respective areas of the upper membrane **406** and lower surface **408** in equal ratios only in the optically active region. In particular, a substantially equal optical energy (i.e., a product of area times a reflectivity) may be created. Along these lines, the membrane design in other areas can be freed from optical constraints. Accordingly, this portion of the design can then be optimized to enhance the modulator performance, such as the modulator speed.

FIG. 5 is a top view of a light modulator structure **500** according to a first embodiment. This particular example includes ribbon-type diffractive elements **502** fabricated to be situated above a substrate **501**. In this example, the ribbons **502** are configured to be wider **507** near the support structures **504**. This results in more pull-down force in this non-optical region **506** because the controllably-induced force (for

example, a controlled electrostatic force) that pulls-down the ribbons **502** is typically proportional to the surface area of the region. This can result in more bending of the ribbons **502** at their wider (and more substantial) portions **507** in this non-optical area **506**, but less bending of the ribbons at their narrower portions **509** in the optical area **508**, as compared to a previous constant width ribbon type of design. The central portion or optically active area **508** includes the thinner reflective ribbon portions and the gaps **510** therebetween opening to a reflective surface below. Because of this increased bending in the non-optical portion **506**, the narrower portions **509** of the ribbons in the optically active area **508** can be substantially flat in this design. This can result in improved modulator contrast and efficiency. Larger ribbon widths typically also increase the damping of the ribbons motions, which can advantageously enable higher speed operation of the modulator.

FIG. 6 is a top view of a light modulator structure **600** according to a second embodiment. This embodiment includes a substantially circular movable membrane **602**. The membrane **602** comprises a compliant material. For example, the membrane **602** may be constructed using a polymeric material, or a metallic material, or a polycrystalline or amorphous material.

The central portion **604** of device may be configured to be illuminated by an incident light beam, so it is an optically active area. The other (non-optically active) regions **606** may surround the central portion **604** and can be designed to optimize for speed and/or damping characteristics. In order to obtain high device switching speed, the device can be configured for high resonant frequency and high damping characteristics. Overall, the design can provide for a substantially flat optically active

area **604**. The area **606** outside of the optical "sweet spot" can be designed (perhaps, for example, with appropriately configured gaps) to mitigate any "overfill" of the optical area **604** by the illumination system.

The optically active area **604** in FIG. 6 is shown to include gaps (holes) **608** in the reflective upper membrane **610** within that area **604** to expose the lower reflective surface. The reflectivity of the upper membrane and the lower surface may be provided by a layer of reflective material, such as aluminum or other metal. These are shown as triangular in shape, but they could be rectangular, circular, rectangular, square, or any suitable shape. Also, the membrane in general, although shown as substantially circular, could also be implemented in a rectangular or substantially any suitable shape. The array of openings in the membrane may be configured to have various symmetries, including 2-fold, 3-fold, 4-fold, 6-fold, or n-fold symmetries. Specifically, for example, the array of openings may be in a two-dimensional version of a "simple cubic" array, or in a two-dimensional version of a "face centered cubic" array, or in other forms of two-dimensional arrays.

While specific embodiments of the present invention have been provided, it is to be understood that these embodiments are for illustration purposes and not limiting. Many additional embodiments will be apparent to persons of ordinary skill in the art reading this disclosure.